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A solution to CO_2 geological storage problems in Japan : To realizing "Japan-type CCS"

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Abstract

Geological structure of the Japanese Islands is very complex because that is located in front of the subduction zone of the Pacific Plate and Philippine Sea Plate. The geological storage project near the emission source in Japan must target relatively younger formations. In this circumstance, there are the specific geological problems of Japan that must be solved.

1) Sealing efficiency of the seal formation (mechanical stability and large porosities).
2) Uncertainty of CO_2 movement in the inhomogeneous reservoir.
3) Treatment of the active faults and folds that form the basins (i.e. reservoirs).
4) Small capacities of one reservoir (basins).

We have conducted several study to solve its geological problems and to build "Japan-type CCS".

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Keywords:;,Japan-type CCS; Storage near the emission source; Distributed CCS; Sealing Efficiency

1. Introduction

To achieve the CCS in Japan, the reduction of the cost for transportation is indispensable. Especially, "high transportation cost" makes the specific problem caused by the geographical situation and social restrictions of Japan. Thus, it is important to develop the aquifers near the emission sources such as thermal power plants or steelworks plants.

From now, the research project of "Innovative Zero-emission Coal Gasification Power Generation Project" has been performed mainly by New Energy and Industrial Technology Development Organization (NEDO), a Japanese independent administrative agency. In this project, a serious of total system techniques including separation, capture, transportation and storage are examined with planning demonstration experiment of an exhausted gas-field as a test site. On the other hands, the examination for the possibility of CCS near the large emission source targeting on the commercial site in future has not been progressed so much.

As members of a branch office of Institute of Innovative Technology for Earth (RITE), during the period from 2005 to 2008, the authors have investigated the possibility of the storage in deep saline aquifers of Japan near the large emission sources. The results show the possible storage capacities about 30Gt-CO_2 in the prospective basins such as Osaka Bay or Ise Bay area [1]. In addition, it can be recognized that the targets of the reservoirs in Japan mainly consist of relatively younger formations formed in Plio-Pleistocene (from 0.78 to 5.2 Ma). As most of European and American CCS projects target hardly compacted rocks formed in Mesozoic and Paleozoic (from 65 to 400 Ma), the "soft" formation in Japan can be thought as unknown target for CCS. In this case, many geological risks such as the

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seepage or deformation of soft seal formations, complicated CO_2 movement through inhomogeneous reservoirs and the affection of faults can be prospected. These geological problems must be strictly understood not only to estimate of the potential storage capacities, but also to evaluate the safety of CCS business regarding to the fear for CO_2 leakage or induced earthquakes.

2. CO_2 storage in terms of Japanese tectonic setting

The Japanese Islands is located in front of the subduction zone where the Pacific Plate or Philippine Sea plate is slipped under the crust. Thus, they are strongly influenced from the tectonic movement, and have complicated geological structure with many faults and folds. On the other hands, the main parts of Europe and America consist of stable crusts which have not been suffered by large structural movement in long terms, and their geological structures are relatively simple with few faults or deformations.

Figure 1 shows the comparison between the geological sections of the Grand Canyon in western part of America (Utah/Arizona) and the Tohoku-region of Japan in almost same scales [2]. As for the Grand Canyon, the sedimentation of the formations is almost horizontal and sequential while the geology of Japan in almost same age has extremely complicated geological structures. For instance, the attempt to search for the candidate site of CCS in the Tohoku-region shown in the figure reveals that there are no adequate basins except the narrow area after Pliocene on the side of the Sea of Japan.

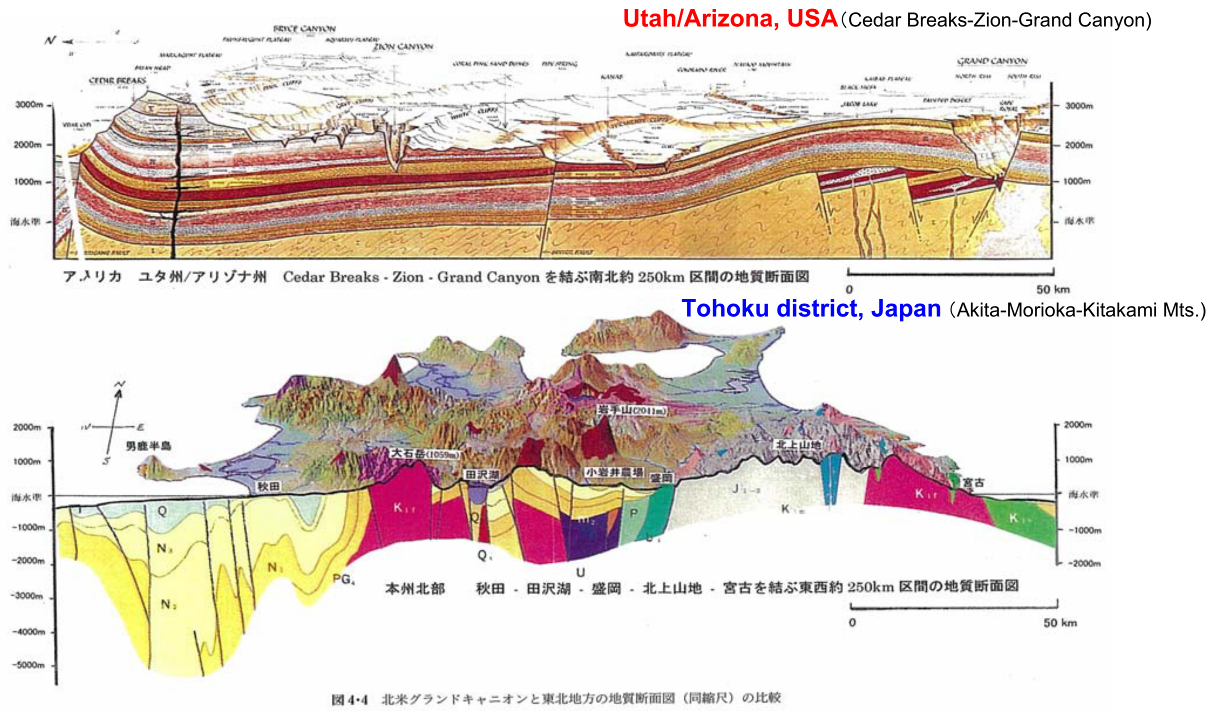

Figure 1 Geology in Japan sometimes very complicated [2])

Figure 2 shows the comparison between the Petrel sub-basin of Australian CCS Project and the geological structure of Osaka Bay area of Japan [3, 4]. In Petrel sub-basin, the old formations of Jurassic-Cretaceous, Mesozoic lie in an orderly manner, and aquifer and seal formations are constituted by these formations. On the other hand, in Japan, this type of horizontal and sequential formations must be found out only in the younger strata after Pliocene such as the Osaka group.

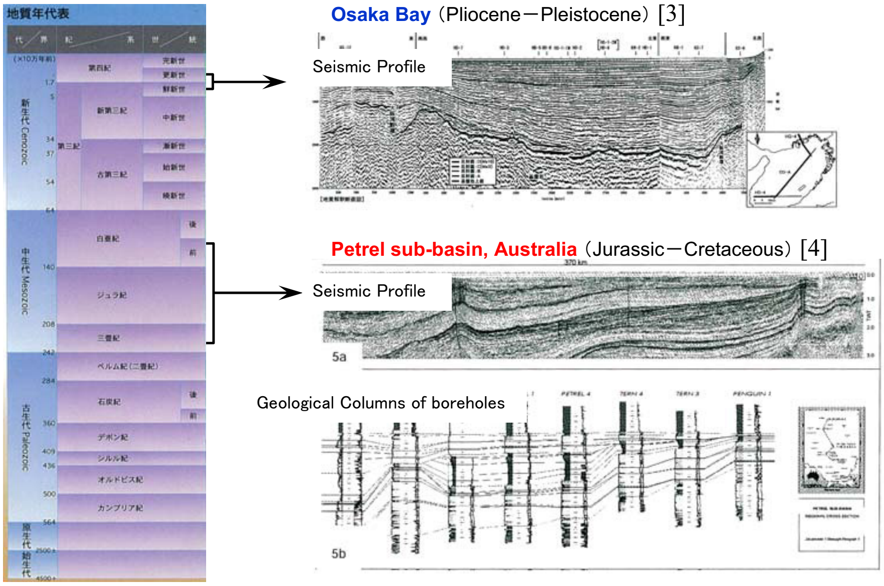

Figure 2 Typical age of Japanese deep saline aquifers and Petrel Sub-basin, Australia

3. Geological age of deep saline aquifers

The geological ages of deep saline aquifers for CCS project by various countries are listed in Figure 3. These project data are derived from the IPCC special report (2005) [5] and presentations in the poster session of GHGT9 (2008) [6]. According to the list, most part of CCS projects performed or planed mainly in Europe and America target the hardly compacted rocks in the period between early Paleozoic and Mesozoic (from 400 to 65 Ma). On the other hand, the Nagaoka project in Japan targeted the Haizume formation in late Quaternary, Pleistocene as aquifer formation which is extremely younger than those in European and American countries.

Figure 4 shows the prospective sites for deep saline aquifer near the large emission sources which were extracted by now [7]. Most of them are the sedimentary basins in the relatively early age between Pliocene, Neogene and Pleistocene, Quaternary (from 0.78 to 5.2 Ma).

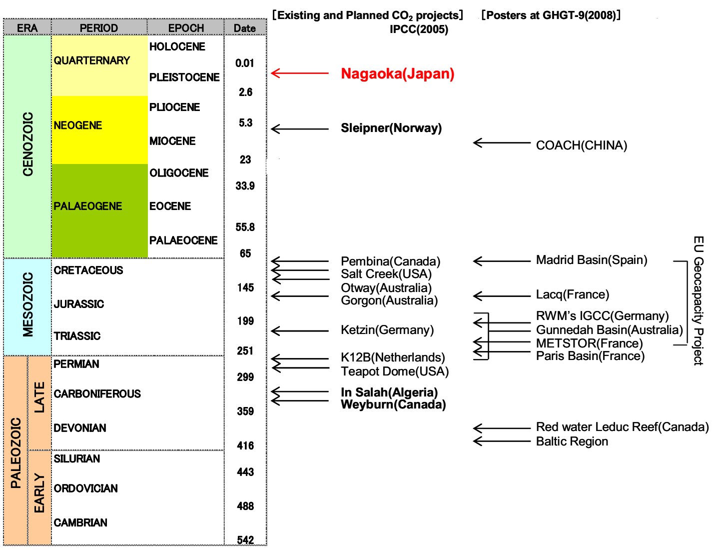

Figure 3 Geological age of Deep Saline Aquifers in different countries CCS projects [5, 6].

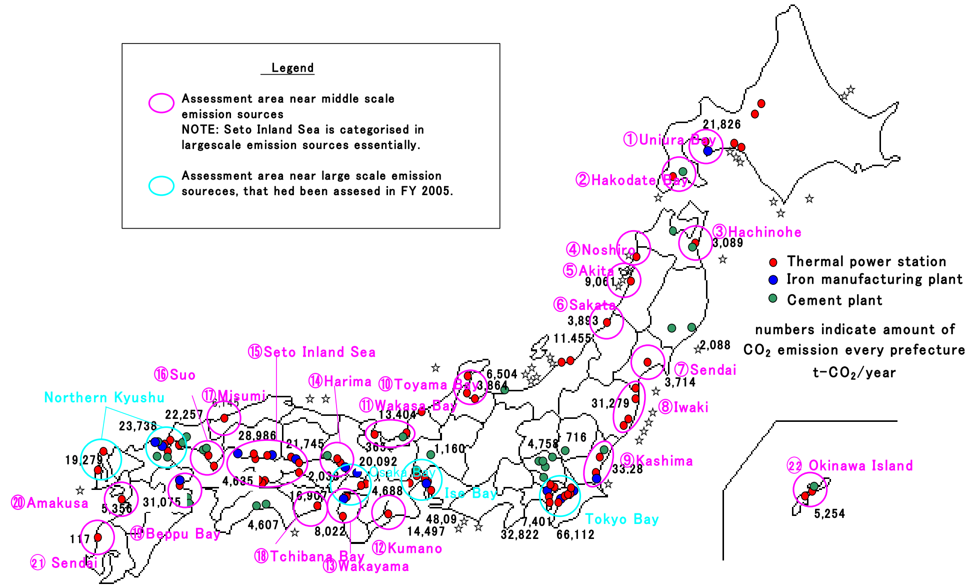

Figure 4 Locations of investigated deep saline aquifers in the vicinity of major CO_2 emission sources [7]

4. A case study on the storage in deep saline aquifer in Japan

In Osaka bay area which is one of the prospective sites for the storage in deep saline aquifer, the formation named as the Osaka group in Plio-Pleistocene is distributed. The Osaka group is inter-bedded by tuff layers and marine clay layers (numbered by Ma-1–Ma12) that can be treated as key beds. By the boring exploration, the facies of the formations are changed by the boundary of Ma-1 (the lowest marine clay layer). Under Ma-1, the formation consists of fluvial deposits of gravel, sand silt, while the formation above Ma-1 consists of many marine clay layers (see Figure 5[3]). Depending on the general facies of Osaka group, the CO_2 geological storage model can be designed which is constituted by the fluvial deposits under Ma-1 as aquifer formation and the formations with thick marine clay layers as seal formation (see Figure 6[8]).

According to the data of the seismic prospecting by reflection method, these relations between seal and aquifer formations are widely successive. The basin is bounded by the active fault named as the Osaka Bay Fault (see Figure.7[9]).

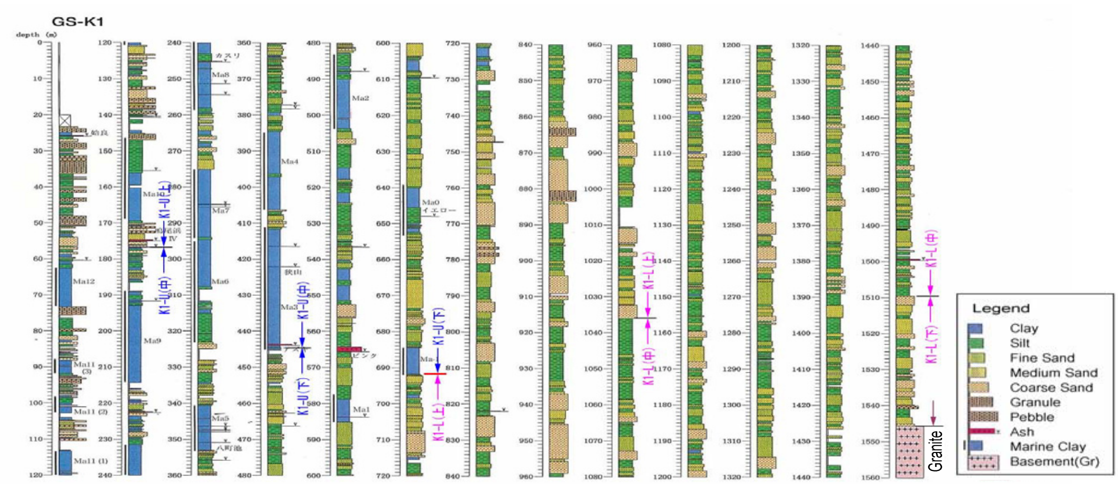

Figure 5 Geological column of borehole along the Osaka bay to depth of 1,700m [3]

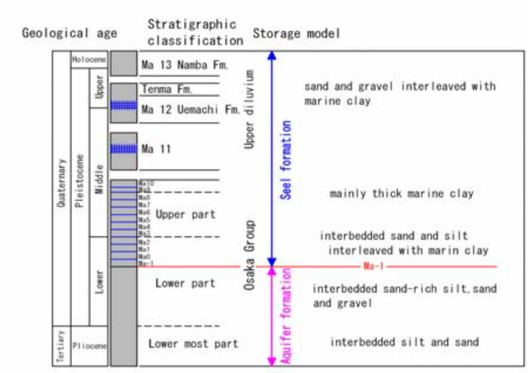

Figure 6 CO_2 storage model based on facies of Osaka group [8]

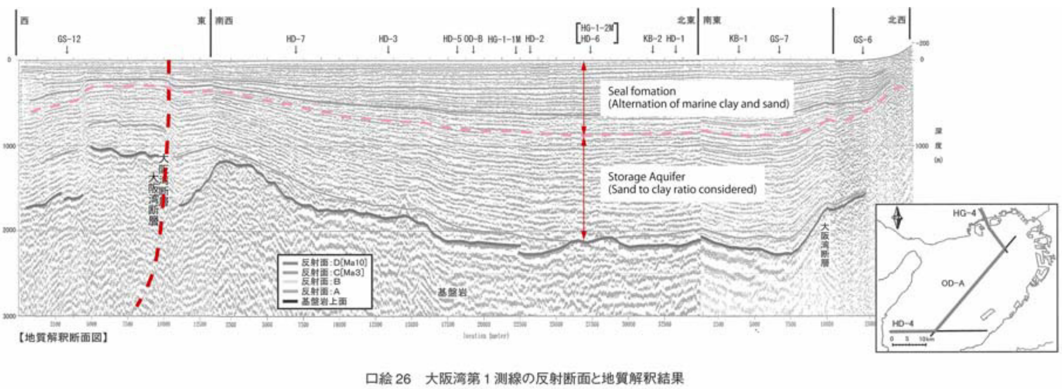

Figure 7 Geological cross section and CO_2 storage model [3]

5. Geological problems on the CO_2 storage in Japan

The geological storage project near the emission source in Japan must target the “soft” layers which have been rarely targeted in the universe. In this circumstance, the specific geological problem of Japan as follows must be considered.

1) Sealing efficiency of the seal formation (mechanical stability and large porosities)

Neogene and Quaternary formations in Japan, are generally consisting of soft rock or low-cemented sediment. In the case of Osaka group, Uniconfined compressive strength of marine clay is 10MPa or less. On the injection of CO_2 into the soft formations of Japan, there is a fear that seal layers might be deformed or failed as the pressure of CO_2 under the seal layer would exceed the yielding pressure or shear strength of the seal formations.

In addition, the soft formation may have small capillary sealing efficiency because of their large porosities, and thus there is a fear that CO_2 would penetrate through the seal formation.

2) Uncertainty of CO_2 movement in the inhomogeneous reservoir

Most of deep saline aquifers of Japan near the large emission sources are consisting of lake deposits or fluvial deposits (see Figure 5). The movement of CO_2 may be difficult to predict because of the inhomogeneity on the reservoir formations that consist of the alternated deposits of gravel, sand and silt. In such inhomogeneous formations to predict the movement of CO_2, we need to have a detailed method of hydrogeological modeling.

3) Treatment of the active faults and folds that form the basins (i.e. reservoirs)

Most of basins which are considered as CO_2 reservoir were formed by tectonic movement after Neogene and were strongly related with the active faults and folds. As the active faults have moved repeatedly after early Quaternary and the crushed zones or damaged zones were developed near the faults, the faults trapping mechanism of Petroleum reservoir engineering cannot be applied simply. The problem of induced earthquakes by injection of CO_2, also has been discussed.

4) Small capacities of one reservoir (basins)

Generally one basin is small, because geological structure is very complex in Japan. Therefore, we think that distributed CCS should be established, rather than large centralized CCS.

6. Case studies on the risk assessment for "Japan-type CCS"

6.1 Mechanical stability of soft seal formations

Mechanical stability on the sealing formation (marine clay) of the Osaka Basin, which is one of the typical soft grounds in Japan, was studied[9]. In this study, using the analytical model shown in Figure 8, the numerical simulation of CO_2 injection was conducted, and the distribution of CO_2 (see Figure 9) and the uplift pressure to the seal formation (see Figure 10) was obtained. Using the uplift pressure as input data, the coupling analysis of seepage and deformation was conducted to estimate the stress change by CO_2 injection. As the result, the sear stresses occurred in the seal formation by CO_2 injection are as much as 1/100 of shear strength of the seal formation (see Figure 11) and thus the seal formation of the Osaka Basin can be thought as sufficient in mechanical stability.

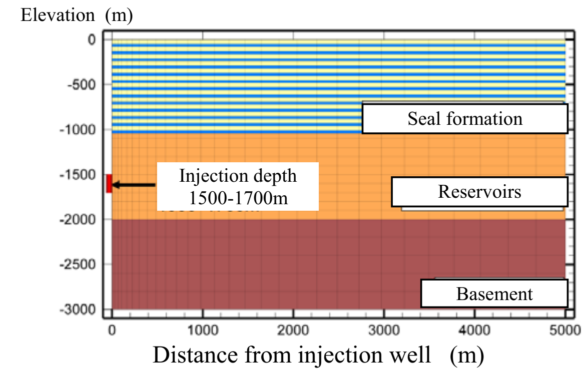

Figure 8 Analysis model of Osaka group [9]

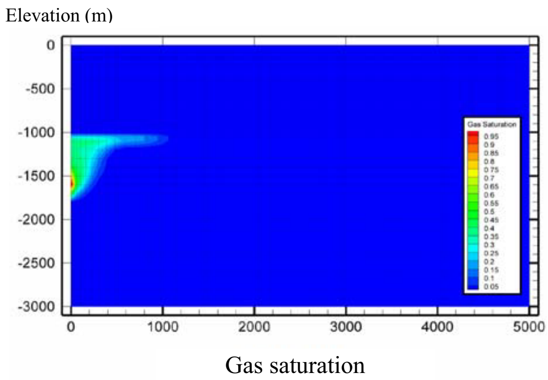

Figure 9 An example of the results of two-phase flow analysis (Injection is on the rate of 1Mt-CO_2/year during 30 years) [9]

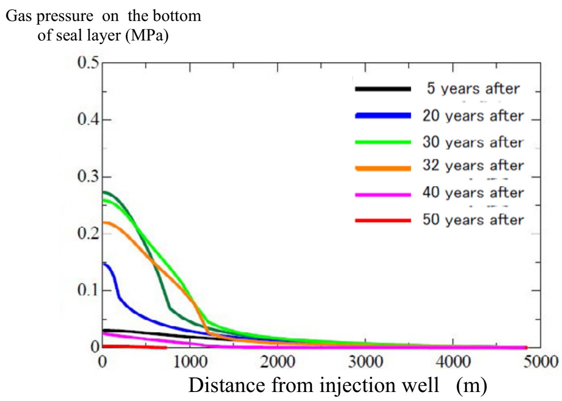

Figure 10 Uplift pressure to the seal formation by buoyancy of CO_2 [9]

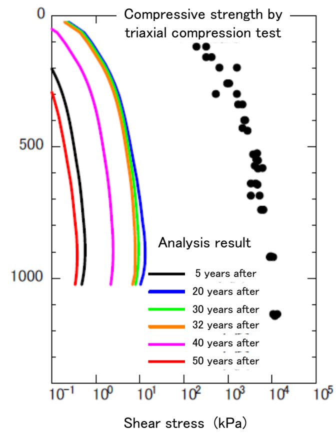

Figure 11 Comparison between the shear strength of the seal formation and induced shear stress by the injection of CO_2 [9]

6-2 Sealing efficiency of soft seal formations

Figure 12 shows the relations between entry pressures and porosities on various types of rocks and soils. The entry pressures increase with the decrease of the porosities. The rocks other than Japanese have the porosities ranging from 0.1% to 30%. On the other hand the porosities of soft mudstones in Japan range from 20 to 60%. The larger porosities of the mudstones in Japan may be caused by their younger ages. Besides of such larger porosities, the entry pressures of the soft mudstones in Japan are almost equal (or slightly lower) to those of the older rocks. These gaps are caused by the micro fabric formed during sedimentation in marine and their diagenetic change by consolidation during the increment of overburden pressure [10].

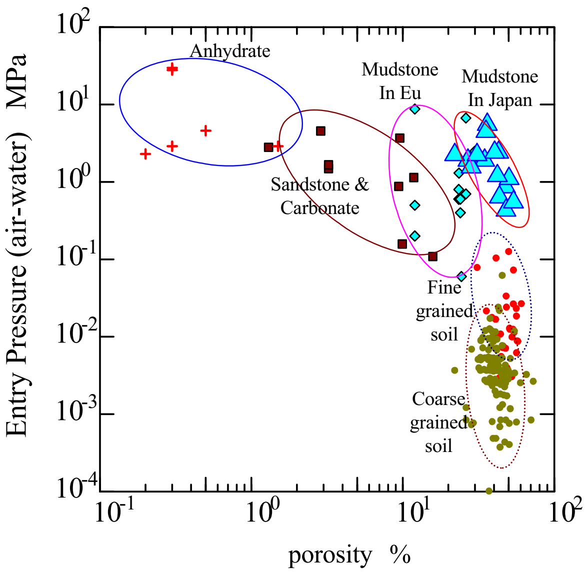

Figure12 Relations between porosity and entry pressure [10].

6.2 Accurate reservoir models using seismic inversion and rock phygics

The depth of the target aquifers is not less than 800m, so that seismic reflection method is the most effective tools to investigate a geological structure. Especially in the inhomogeneous reservoir of Japan , the seismic method can provide with reservoir properties using seismic inversion with log analysis. Thus we have conducted preliminary study and evaluated a potential of saline aquifer as a CO_2 reservoir[11].

First, we calculated acoustic impedance distribution (see Figure14) by inverse analysis, using the section of refraction seismic survey data (see Figure13). Second, in order to convert acoustic impedance distribution into porosity distribution, we calculated theoretical relationship between these by the rock physics model. Porosity obtained from density log and acoustic impedance are cross-plotted in Figure15. According to this figure, sandstone and mudstone show each different trend, and explained by linear expression respectively. We regard the area has lower porosity than cross point of two trend lines in figure15 as sandstone area, and depicted porosity distribution of sandstone area in the reservoir (see Figure16).

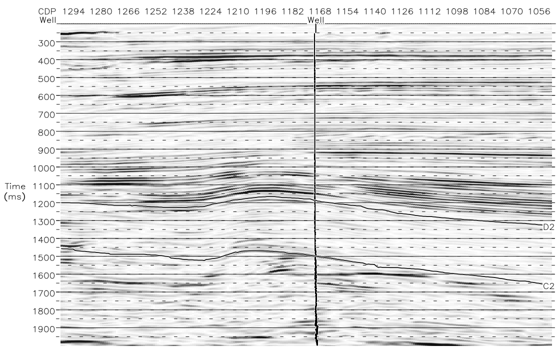

Figure13 Applied refraction seismic survey data[11]

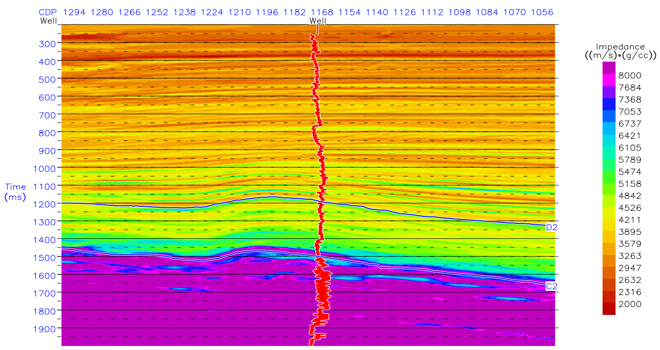

Figure14 Acoustic impedance distribution from seismic inversion [11]

Natural radioactivity

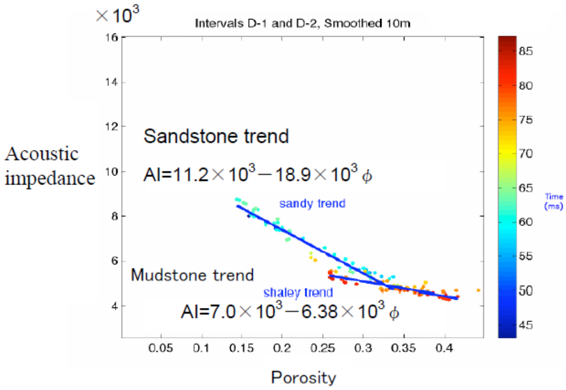

Figure15 Relations between porosity and acoustic impedance [11].

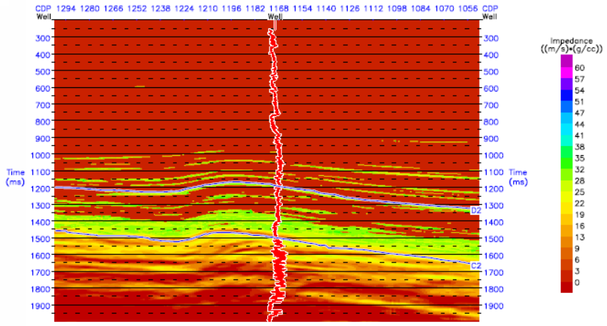

Figure16 Porosity distribution of sandstone area [11].

7. Conclusion

- “High transportation cost” makes the specific problem caused by the geographical situation and social restrictions of Japan.
- It is important to develop the aquifers near the emission sources such as thermal power plants.
- The examination for the possibility of CCS near the large emission source targeting on the commercial site in future has not been progressed so much.
- We have investigated the possibility of the storage in deep saline aquifers of Japan near the large emission sources. It can be recognized that the targets of the reservoirs in Japan mainly consist of relatively younger formations (Plio-Pleistocene).
- The geological storage project near the emission source in Japan must target the “soft” layers which have been rarely targeted in the universe. In this circumstance, the specific geological problem of Japan as follows must be considered.
  1) Sealing efficiency of the seal formation (mechanical stability and large porosities).
  2) Uncertainty of CO_2 movement in the inhomogeneous reservoir.
  3) Treatment of the active faults and folds that form the basins (i.e. reservoirs).
  4) Small capacities of one reservoir (basins).
- We have conducted several study to solve its geological problems and to build “Japan-type CCS”.However, the problem of active fault have not been studied enough yet.

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